Spokesman's introduction

K. Long, 6 February, 2020

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PUBLICATION UPDATE

September 23, 2019 Muon Ionization Cooling Experiment RAL-P-2019-003

First demonstration of ionization cooling by the Muon Ionization Cooling Experiment

MICE collaboration

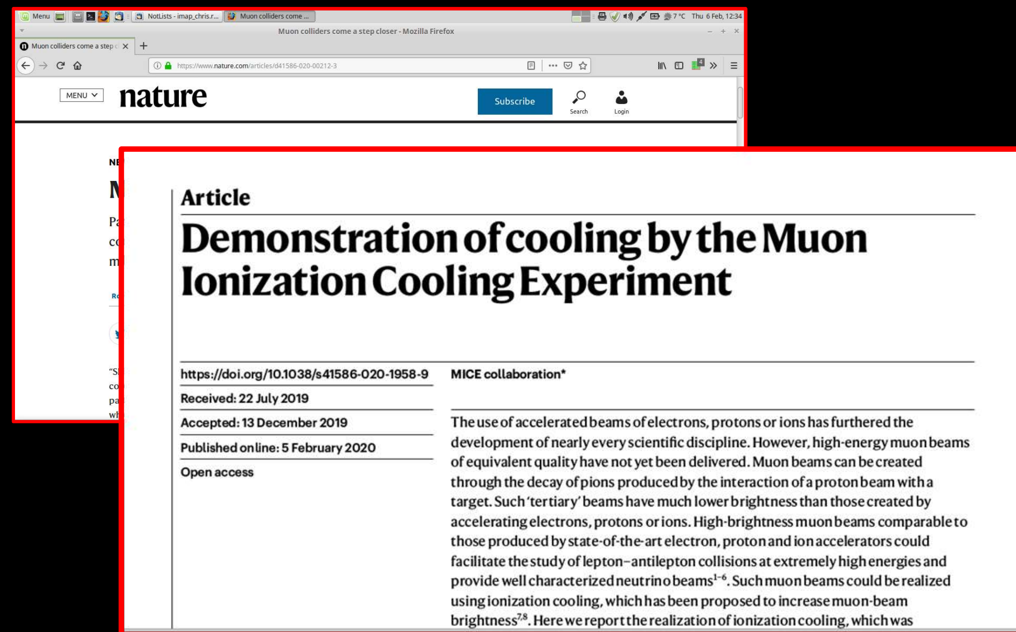
High-brightness muon beams of energy comparable to those produced by state-of-the-art electron, proton and ion accelerators have yet to be realised. Such beams have the potential to carry the search for new phenomena in lepton-antilepton collisions to extremely high energy and also to provide uniquely well-characterised neutrino beams. A muon beam may be created through the decay of pions produced in the interaction of a proton beam with a target. To produce a high-brightness beam from such a source requires that the phase space volume occupied by the muons be reduced (cooled). Ionization cooling is the novel technique by which it is proposed to cool the beam. The Muon Ionization Cooling Experiment collaboration has constructed a section of an ionization cooling cell and used it to provide the first demonstration of ionization cooling. We present these ground-breaking measurements.

Fundamental insights into the structure of matter and the nature of its elementary constituents have been obtained using beams of charged particles. The use of time-varying electromagnetic fields to produce sustained acceleration was pioneered in the 1930s [1–6]. Since then, high-energy and high-brightness particle accelerators have delivered electron, proton, and ion beams for applications that range from the search for new phenomena in the interactions of quarks and leptons, to the study of nuclear physics, materials science, and biology.

Muon beams are created using a proton beam striking a target to produce a secondary beam comprising many particle species including pions, kaons and muons. The pions and kaons decay to produce additional muons that are captured by electromagnetic beamline elements to produce a tertiary muon beam. Capture and acceleration must be realised on a time scale compatible with the 2.2 μs muon lifetime at rest. The energy of the muon beam is limited by the energy of the primary proton beam and the intensity is limited by the efficiency with which muons are accepted into the transport channel. High-brightness muon beams have not yet been produced at energies comparable to state-of-the-art electron and proton beams.

Accelerated high-brightness muon beams have been proposed as a source of neutrinos at a neutrino factory and to deliver multi-TeV lepton-antilepton collisions at a muon collider [7–13]. Muons have properties that make them ideal candidates for the delivery of high energy collisions. The muon is a fundamental particle with mass 207 times that of the electron, making collisions possible between beams of muons and anti-muons at energies far in excess of those that can be achieved in an electron-positron collider such as the proposed International Linear Collider [14], the Compact Linear Collider [15–17] or the electron-positron option of the Future Circular Collider [18]. The energy available in collisions between the constituent gluons and quarks in proton-proton collisions is significantly less than the proton-beam energy because the colliding quarks and gluons each carry only a fraction of the proton's momentum. This makes muon colliders attractive to take the study of particle physics beyond the reach of facilities such as the Large Hadron Collider [19].

Most of the proposals for accelerated muon beams exploit the proton-driven muon beam production scheme outlined above. In these proposals the tertiary muon beam has its brightness increased through beam cooling before it is accelerated and stored. Four cooling techniques are in use at particle accelerators: synchrotron radiation cooling [20]; laser cooling [21–23]; stochastic cooling [24, 25]; and electron cooling [26]. In each case the time taken to cool the beam is long compared to the muon lifetime. Frictional cooling of muons, in which muons are electrostatically accelerated through an energy-absorbing medium at energies significantly below an MeV, has been demonstrated but only with low efficiency [27–30].



Article

Demonstration of cooling by the Muon Ionization Cooling Experiment

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MICE collaboration*

The use of accelerated beams of electrons, protons or ions has furthered the development of nearly every scientific discipline. However, high-energy muon beams of equivalent quality have not yet been delivered. Muon beams can be created through the decay of pions produced by the interaction of a proton beam with a target. Such 'tertiary' beams have much lower brightness than those created by accelerating electrons, protons or ions. High-brightness muon beams comparable to those produced by state-of-the-art electron, proton and ion accelerators could facilitate the study of lepton–antilepton collisions at extremely high energies and provide well characterized neutrino beams[1–6]. Such muon beams could be realized using ionization cooling, which has been proposed to increase muon-beam brightness[7,8]. Here we report the realization of ionization cooling, which was

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ANALYSIS UPDATE AND PAPER PLANNING

Publication planning

Title	Contact	Target date		Comments	Target
		01-Feb-20	v21		
		Preliminary	Final	Jan-20	journal
Measurement of multiple Coulomb scattering of muons in lithium hydride	J. Nugent	Jun18; CM51	Apr19	Progress	Euro Phys C? PRAB?
Performance of the MICE diagnostic systems	P. Franchini	Feb19; CM53		KL part of the problem. Commit to new draft for analysis meeting.	
Phase-space density/emittance evolution review paper					
Flip mode	P. Jurg	TBD		Full analysis chain in place.	
Solenoid mode	T. Lord	TBD			
Phase-space density/KDE/6D-emittance evolution	C. Brown	TBD		Thesis published on initial analysis; taken over by C.Brown	
Measurement of multiple Coulomb scattering of muons in LH2	J. Nugent	TBD		Awaits completion of LiH paper	
Field-on measurement of multiple Coulomb scattering	A. Young	TBD		Analysis underway	
LH Scattering	Gavril	TBD		Analysis underway	

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OUT-REACH

to go along with NATURE-paper submission

Outreach to go alongside Nature paper

- Press release:
  - STFC lead, coordinate through existing lab network
    - Need to coordinate at institute level through CB
- Peer-group seminar at RAL
- Event at RAL/DL:
  - Peer-group meeting:
    - MICE results, impact on muon collider/neutrino factory
    - nuSTORM
  - Early-evening public lecture
- Film with Science Animated
- News/article in, e.g., CERN Courier, Symmetry
  - Perhaps also newspaper

Finaised.

27Feb20; 15:00 GMT; RAL and broadcast to DL

Stalled. Reinitiate.

P. Kyberd now underway

Underway

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UPCOMING MEETINGS

Upcoming meetings

- **2020:**
  - **CM56:**
    - **12/13 March 2020 ☥**
  - **CM57:**
    - **October 2020**

☥ —date determined by room availability

- **Analysis workshops:**
  - **Strathclyde: 12/13Feb20**

- **Video conferences:**
  - **06Feb20**